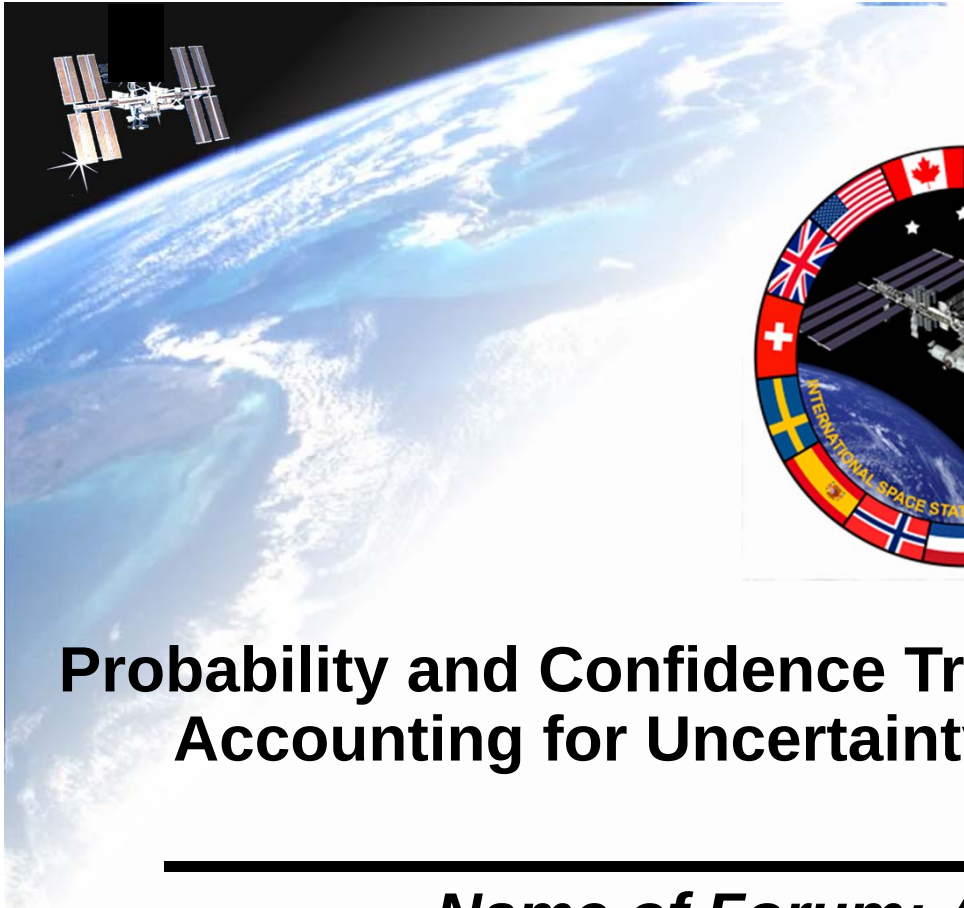




Leif Anderson, Boeing L&M
Neil Box, ARES S&MA
Katrina Carter-Journet, ARES S&MA
Denise DiFilippo, Boeing L&M
Sean Harrington, Boeing L&M
David Jackson, NASA L&M
Michael Lutomski, NASA S&MA

Probability and Confidence Trade-space (PACT) Evaluation: Accounting for Uncertainty in Sparing Assessments

Name of Forum: AIAA SPACE 2012
Conference & Exposition
Date: September 2012

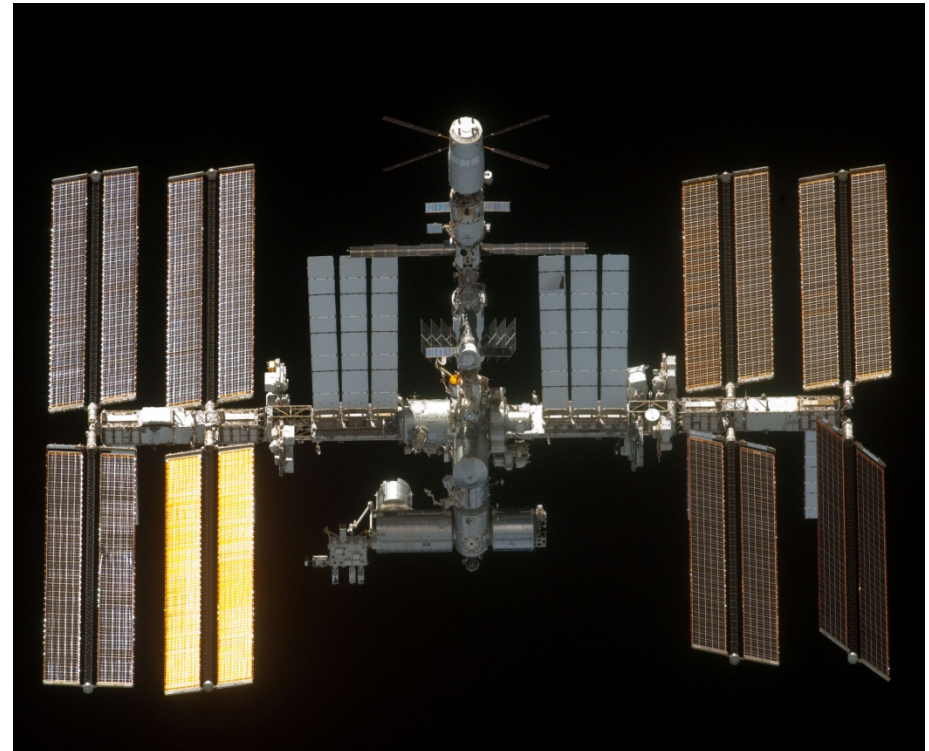




Background



- **Sparing Assessment**
 - Prior to Shuttle retirement, spares had already been purchased and pre-positioned on-orbit to meet the critical ISS functional requirements to the previously expected life of 2015.
 - Currently, an annual assessment is performed to estimate the number of spares needed to keep the International Space Station (ISS) operational until 2020 (and beyond).
 - Historically, the Spares Assessment has not included all uncertainty, specifically epistemic (lack of knowledge).
- **Propose Methodologies to Supplement Sparing Assessment**
 - **Characterize** and **quantify** uncertainty, at the Orbital Replacement Unit (ORU) level.





Problem Statement



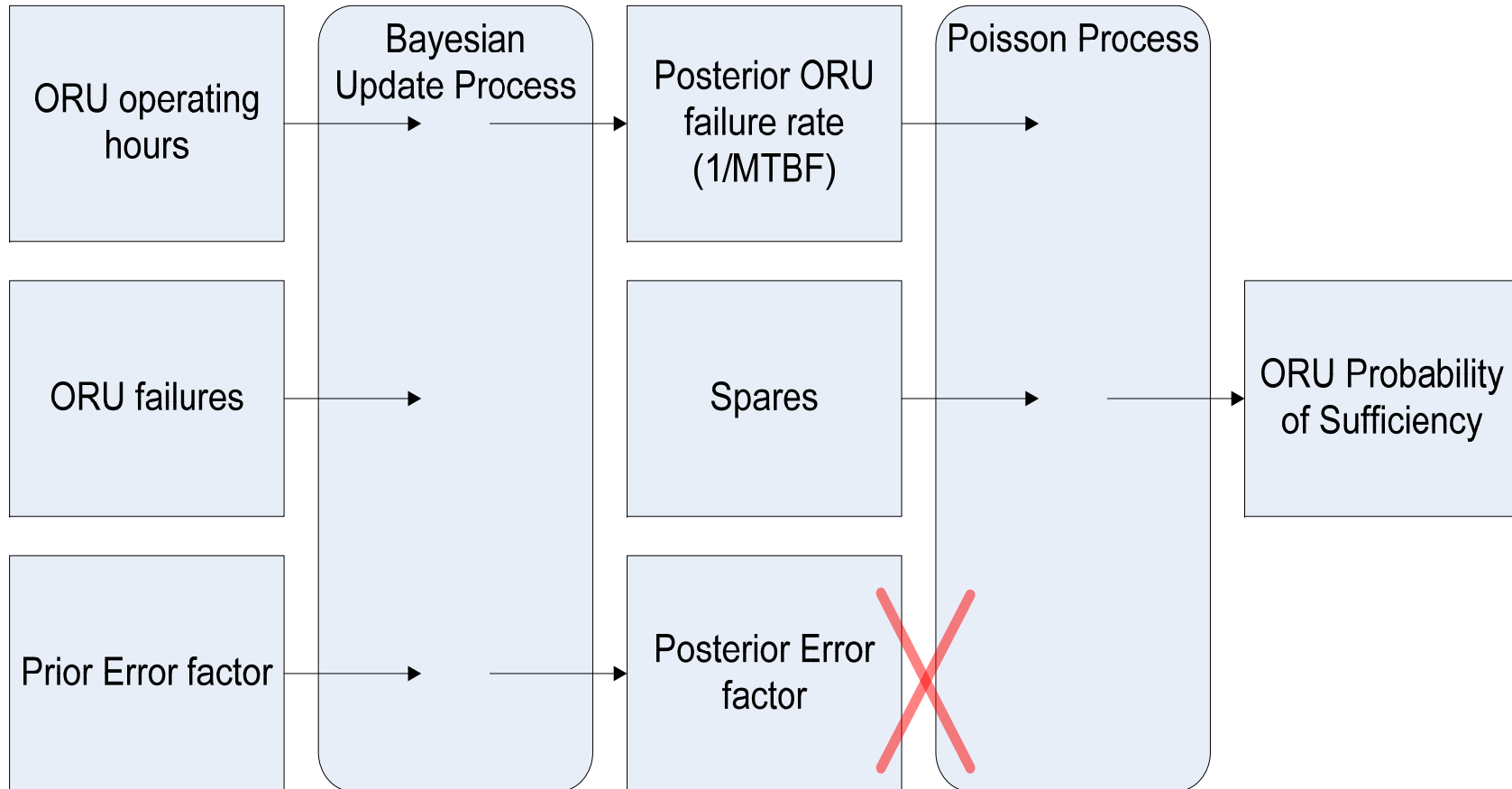
There are two general shortcomings to the current annual sparing assessment:

1. The vehicle functions are currently assessed according to 'confidence targets,' which can be misleading- overly conservative or optimistic.
2. The current confidence levels are arbitrarily determined and do not account for epistemic uncertainty (lack of knowledge) in the ORU failure rate.
 - There are two major categories of uncertainty that impact Sparing Assessment:
 - **Aleatory Uncertainty:** Natural variability in distribution of actual failures around an Mean Time Between Failure (MTBF)
 - **Epistemic Uncertainty** : Lack of knowledge about the true value of an Orbital Replacement Unit's (ORU) MTBF

We propose an approach to revise confidence targets and account for both categories of uncertainty, an approach we call Probability and Confidence Trade-space (PACT) evaluation.

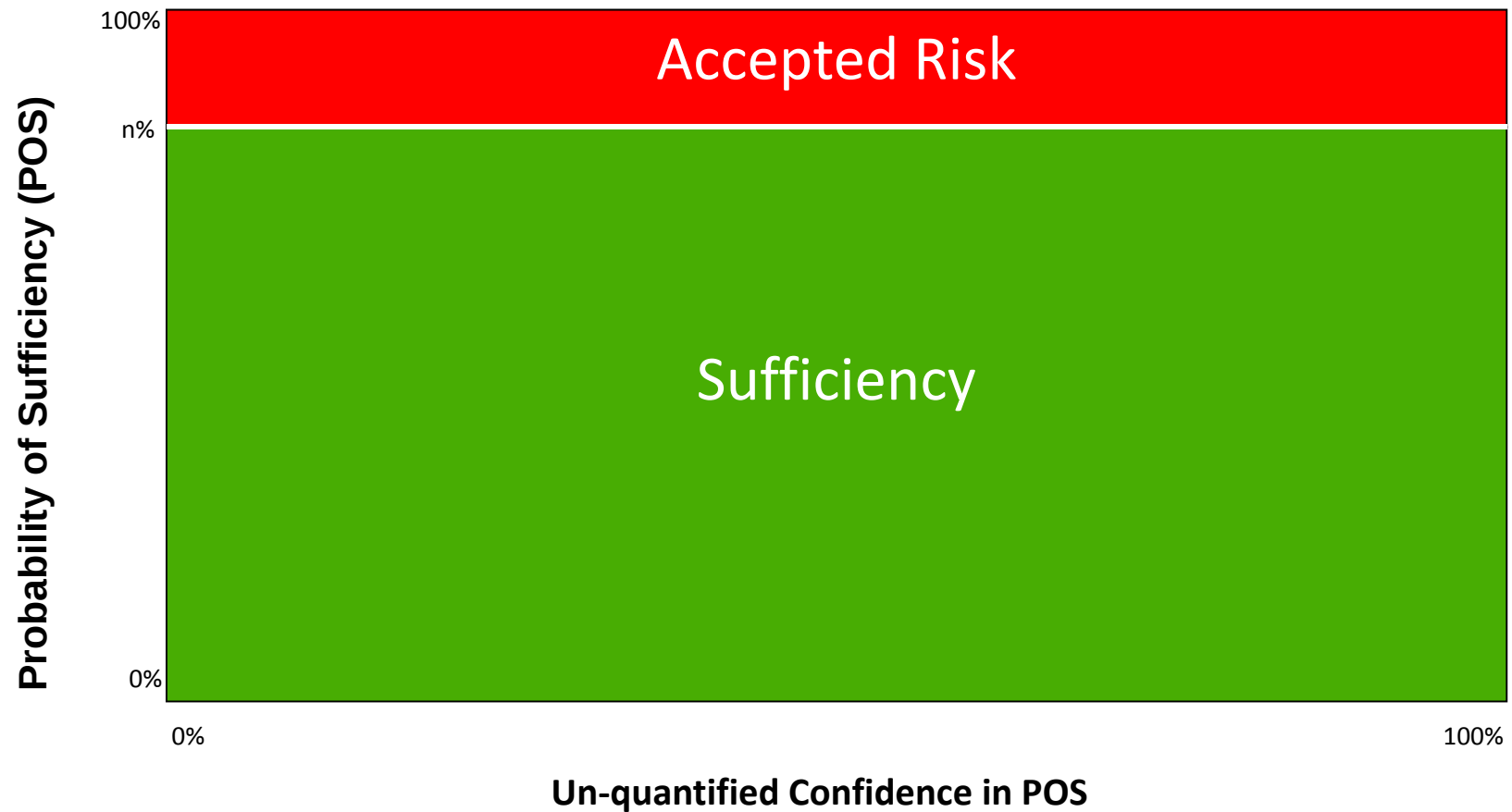


Current Process Flow



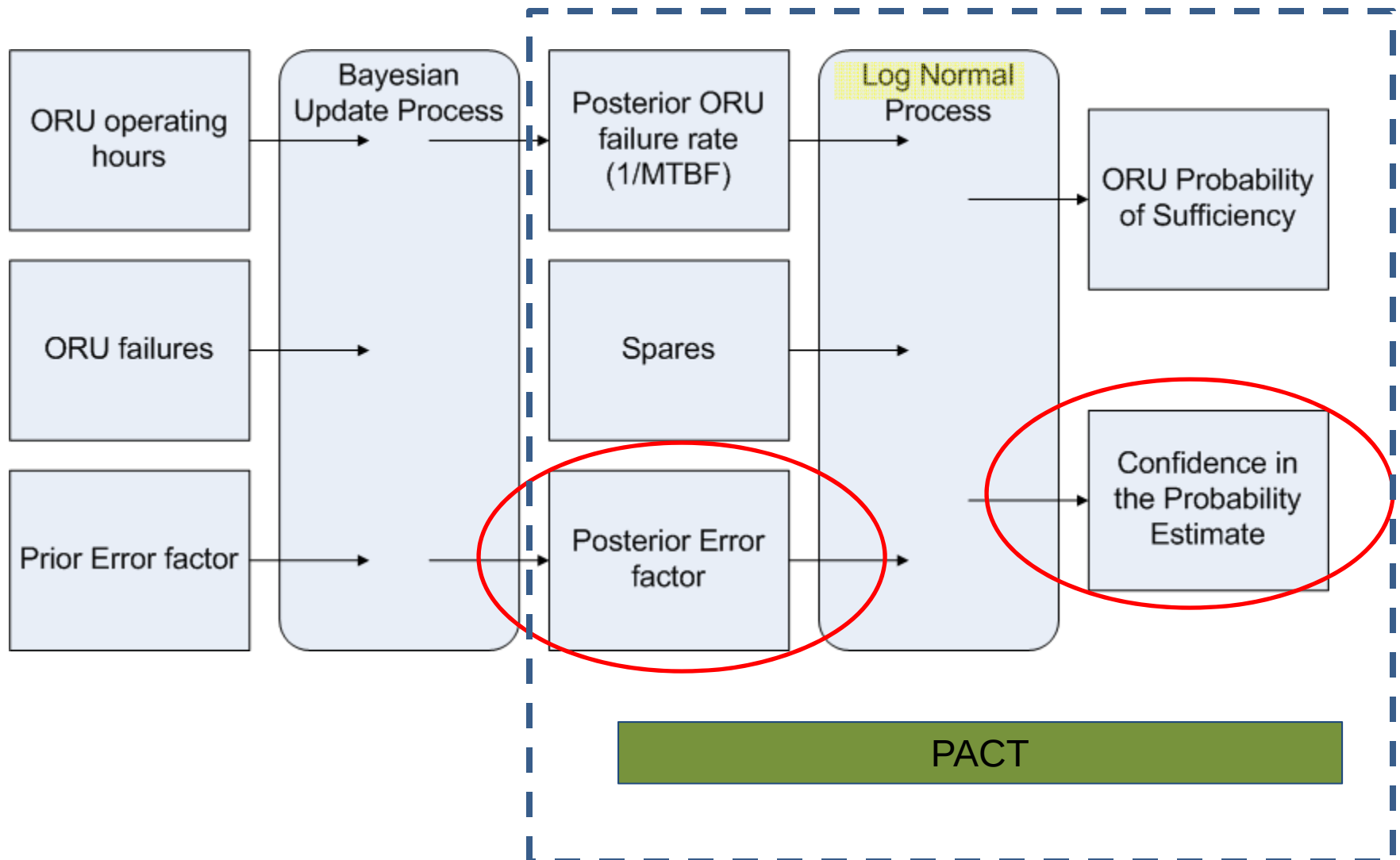


Current Model of ISS Sparing Risk



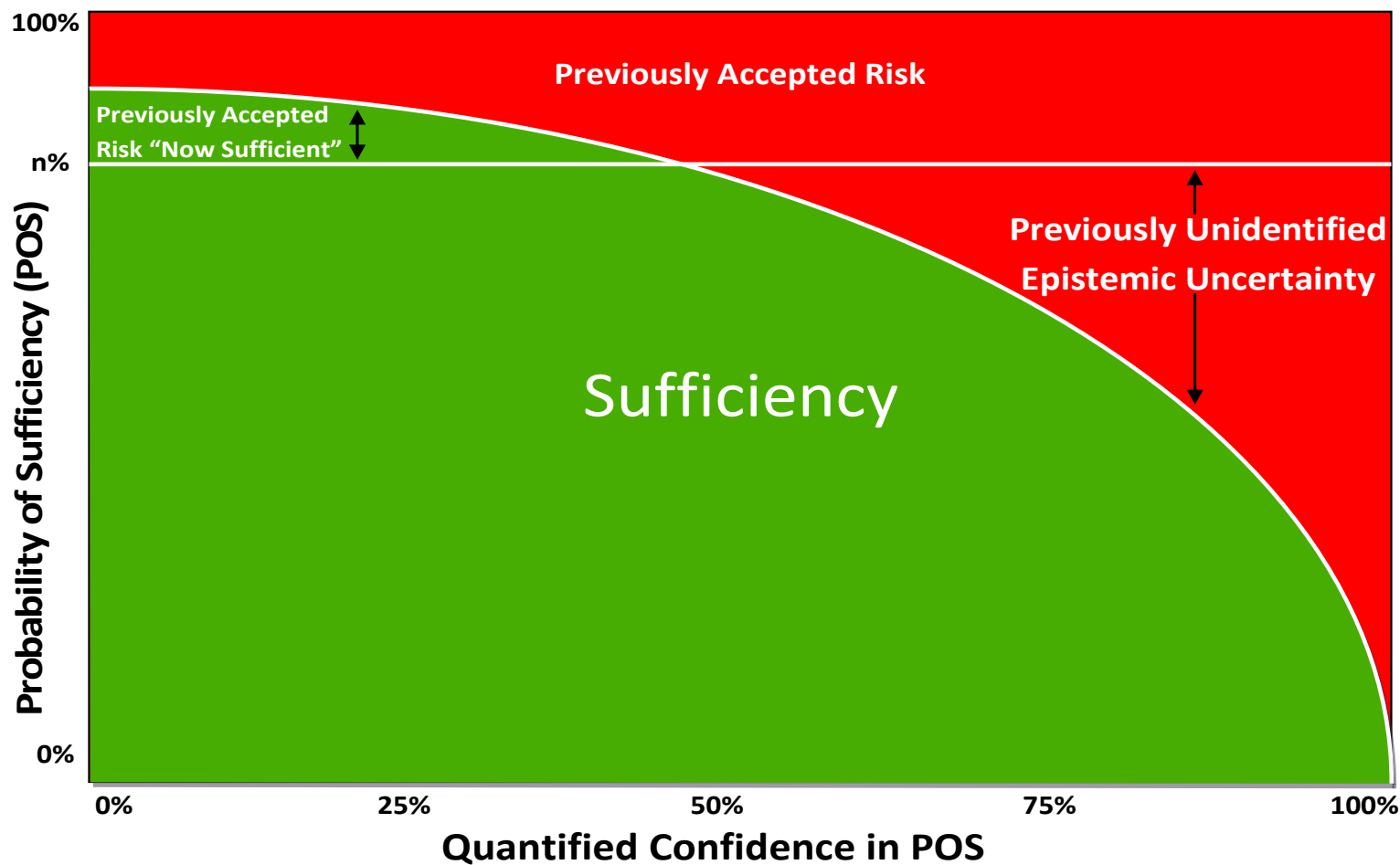


PACT: Proposed Process Flow





PACT Model of ISS Sparing Risk





Benefits of the PACT

- Using this model we can now say- 'we are $n\%$ confident that the ORU has $m\%$ probability of sufficiency through year xxxx.'
- With this knowledge, we can assess the tradeoff along the curve between the *desirable* ORU Probability of Sufficiency (POS) *value* and our *confidence* in the *value*.
 - Decision options:
 1. We may accept the probability and our confidence as is.
 2. We may relax our confidence for a higher desirable POS value, or we may consider a lower desirable POS value in favor of a higher confidence level.

Alternately, we may influence the ORU POS and confidence estimates by assuming additional spares or by changing the projected horizon time for the analysis.



Testing PACT: Generic Example

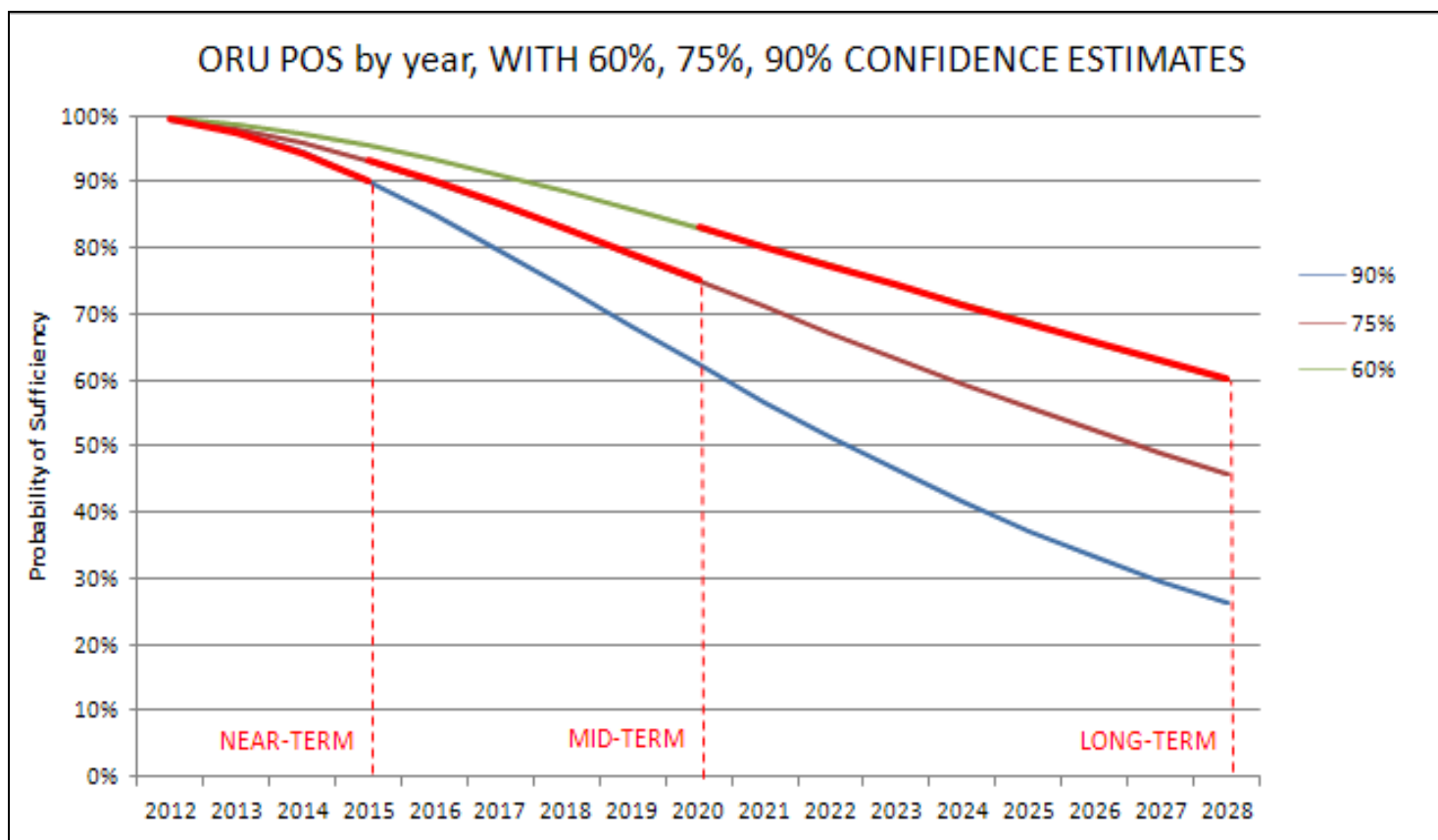


Figure shows what number of 'events' sparing quantities should cover to meet the targets: 90/90 TARGET: 1.36 events, 75/75 TARGET: 1.02 events, 60/60 TARGET: 0.91 events



Summary

- When introducing PACT Evaluation, we define the epistemic uncertainty characterizing ISS sparing assessments. We hereby acknowledge what we can realistically know about an ORU's true failure rate given the various methods used to predict ORU reliability.
- Preliminary results indicate a valuable trade space for selecting optimal targets and identifying the confidence associated with the target.

Acknowledgement:

The researchers extend our utmost gratitude to Dr. William E. Vesely, of NASA Headquarters, whose technical expertise, advice, and encouragement was a catalyst to our efforts for completing this phase of our work.



Backup



Forward Work



1. **Extend the methodology** to evaluate spare allocations for systems and functions to assure a desirable POS and confidence level for short term and long term trade-off
2. Develop the **capability to optimize** resources while assuring a desirable POS and confidence level
3. Evaluate **robust techniques** for determining desirable POS values and associated confidence levels and for handling different plausible error factors in component uncertainties



Testing PACT: Case Study



- **Objective: Selection represents a variety of ISS supportability challenges/risk impacting sparing levels**
 - Demonstrates a breadth of uncertainty: empirical basis of ORU failure rate demonstrated versus lack of operational experience
- **Case Study: 6 ORUs were analyzed in detail to understand the utilization of the proposed process**
 - **Remote Power Control Mechanism (RPCM T5 Ext)** – large population of installed units and spares providing rich operational experience including failures and redesign
 - **Improved Payload Ethernet Hub Gateway (IPEHG)** – small internal ORU, no operational experience
 - **Pump Module Assembly (PMA)** – large external ORU, critical hardware with many hours of operation and a random failure
 - **Hydrogen Dome** – large internal ORU, no redundancy, relatively little operational experience
 - **Solar Array Rotary Joint Drive Lock Assembly Drive Lock Assembly (SARJ-DLA)** – external ORUs with redundancy, similar function differing failure rates, SARJ DLA modeled in the Usable Power function hierarchy
 - **Thermal Radiator Rotary Joint Drive Lock Assembly Drive Lock Assembly (TRRJ-DLA)** – external ORUs with redundancy, similar function differing failure rates, TRRJ DLA modeled as a separate ORU
- **Statistics:**
 - The posterior error factor range for entire ISS population of ORUs: 1.36 – 4.00
 - ORU failure rate range: 1.98E-12 to 3.5E-4 failures/yr



PACT Analyses Results



ORU Name	MTBF	Installed Quantity	kF	Duty Cycle	Total Expected Number of Failures through 2020	Current Number of Spares	Posterior Error Factor	POS through 2020	Confidence at POS
RPCM T5 Ext Improved Payload Ethernet Hub Gateway (IPEHG) Pump Module Assembly (PMA)	268,443	36	1.2	1	12.69	18	1.36	95%	54%
Hydrogen Dome SARJ Drive Lock Assembly (SARJ-DLA)	50,719	3	1.31	1	6.11	3	4	15%	66%
TRRJ Drive Lock Assembly (TRRJ-DLA)	69,065	2	1.2	1	2.74	4	2.87	86%	63%
	49,853	1	1.3	1	2.06	4	4	95%	66%
	278,241	4	1.2	0.5	0.68	2	4	97%	66%
	353,926	4	1.2	0.5	0.53	1	4	90%	66%

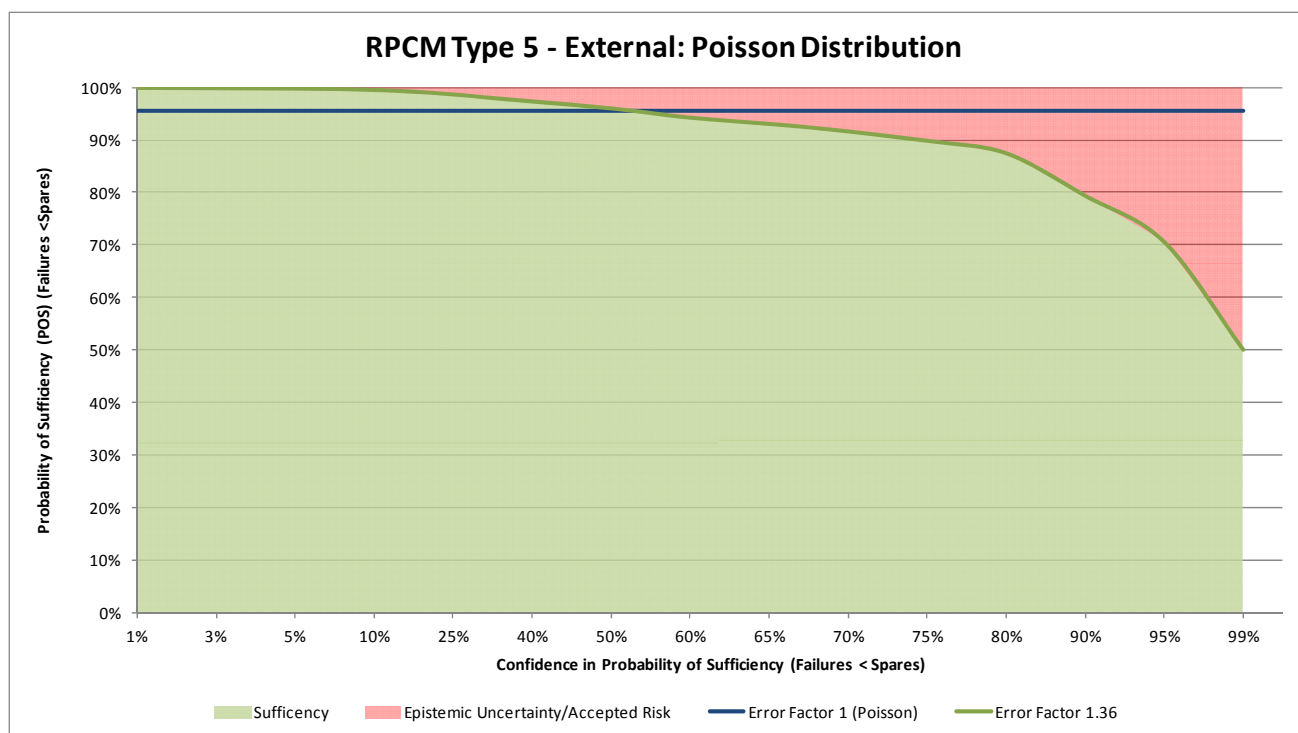
Note: High confidence targets are based on the minimum system configuration for each ORU. The proposed approach will be useful in re-evaluating the POS and identifying a reasonable confidence target.



Results: RPCM Type V Ext



Confidence and Probability of Sufficiency through 2020

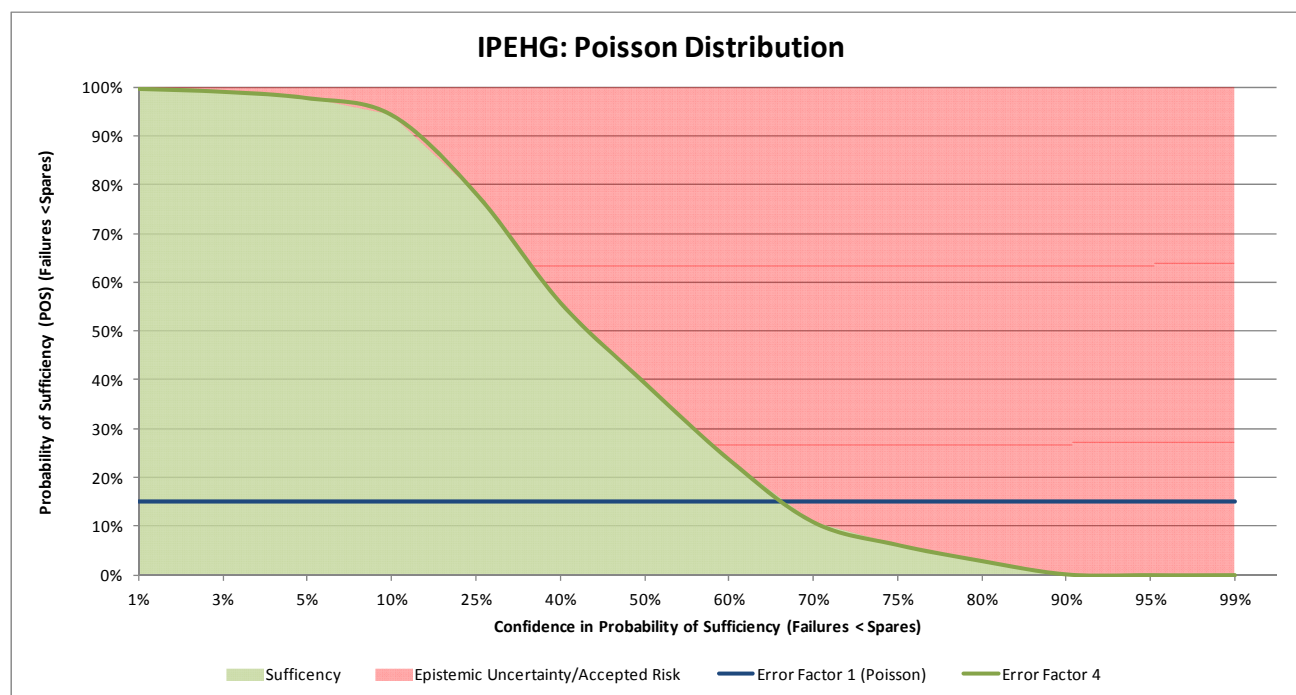




Results: IPEHG



Confidence and Probability of Sufficiency through 2020

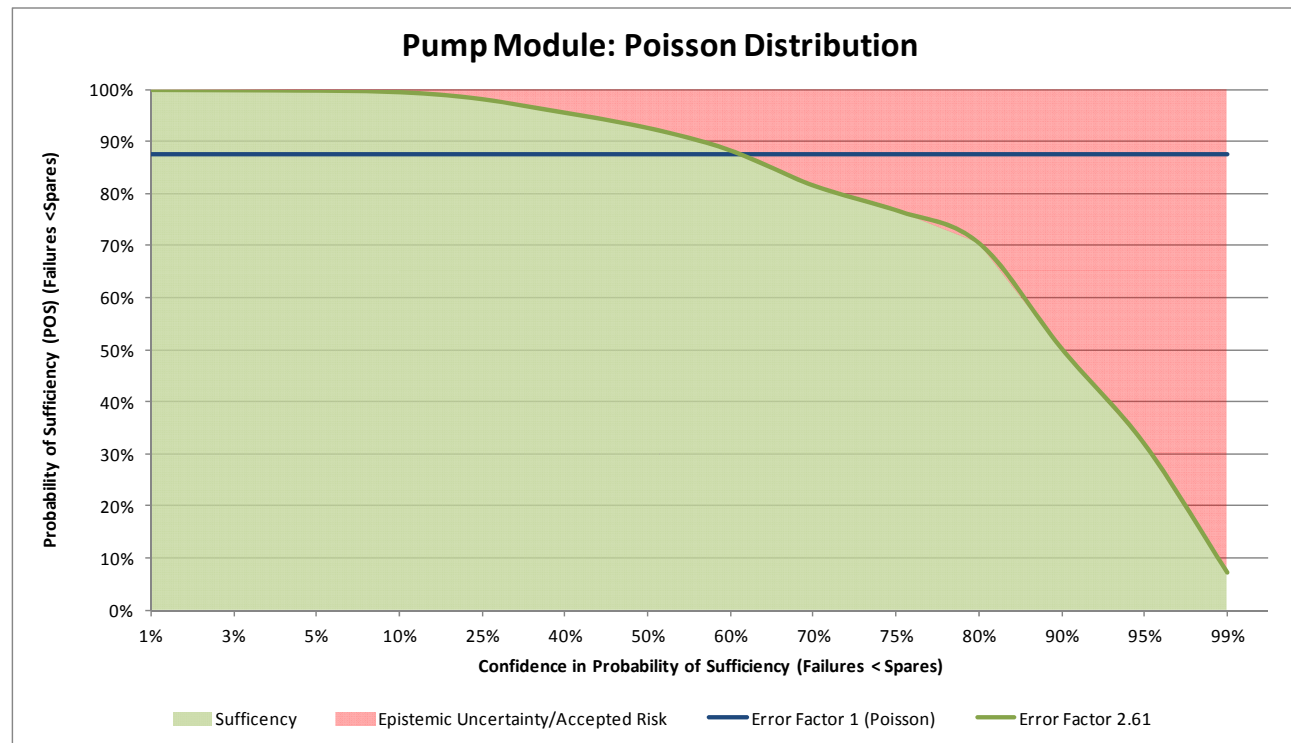




Pump Module



Confidence and Probability of Sufficiency through 2020

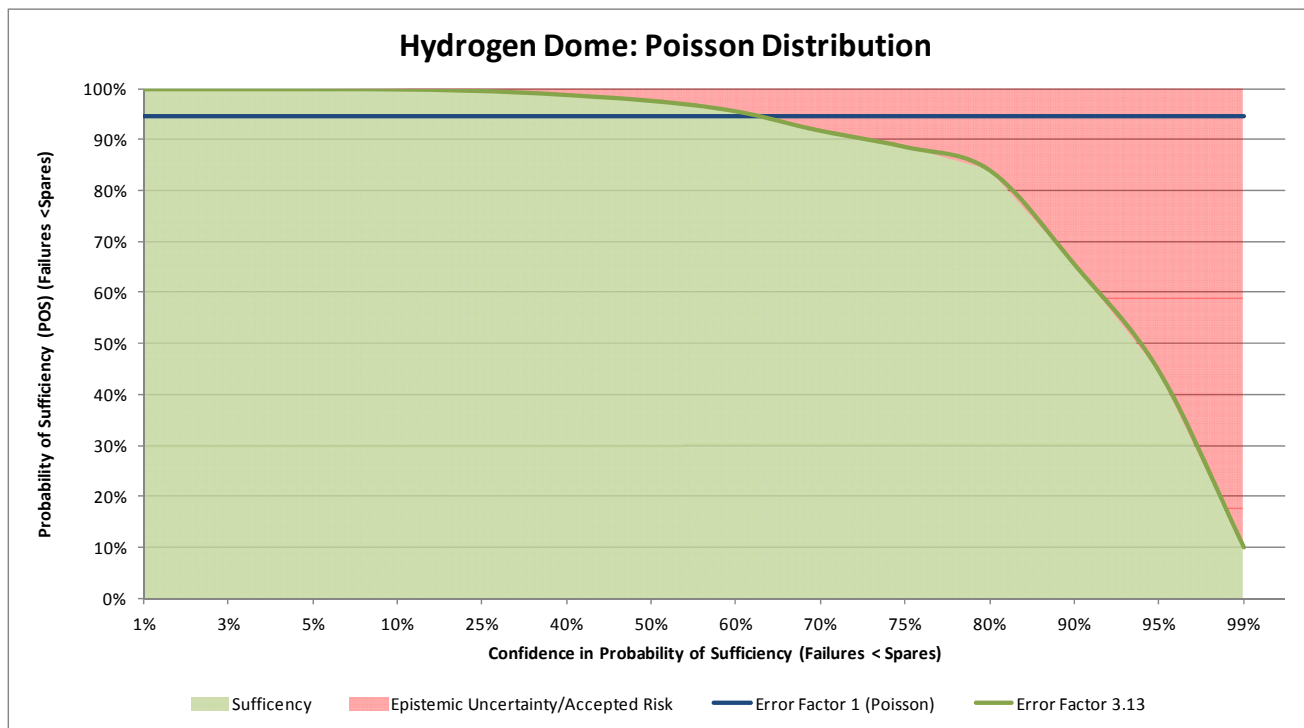




Hydrogen Dome



Confidence and Probability of Sufficiency through 2020

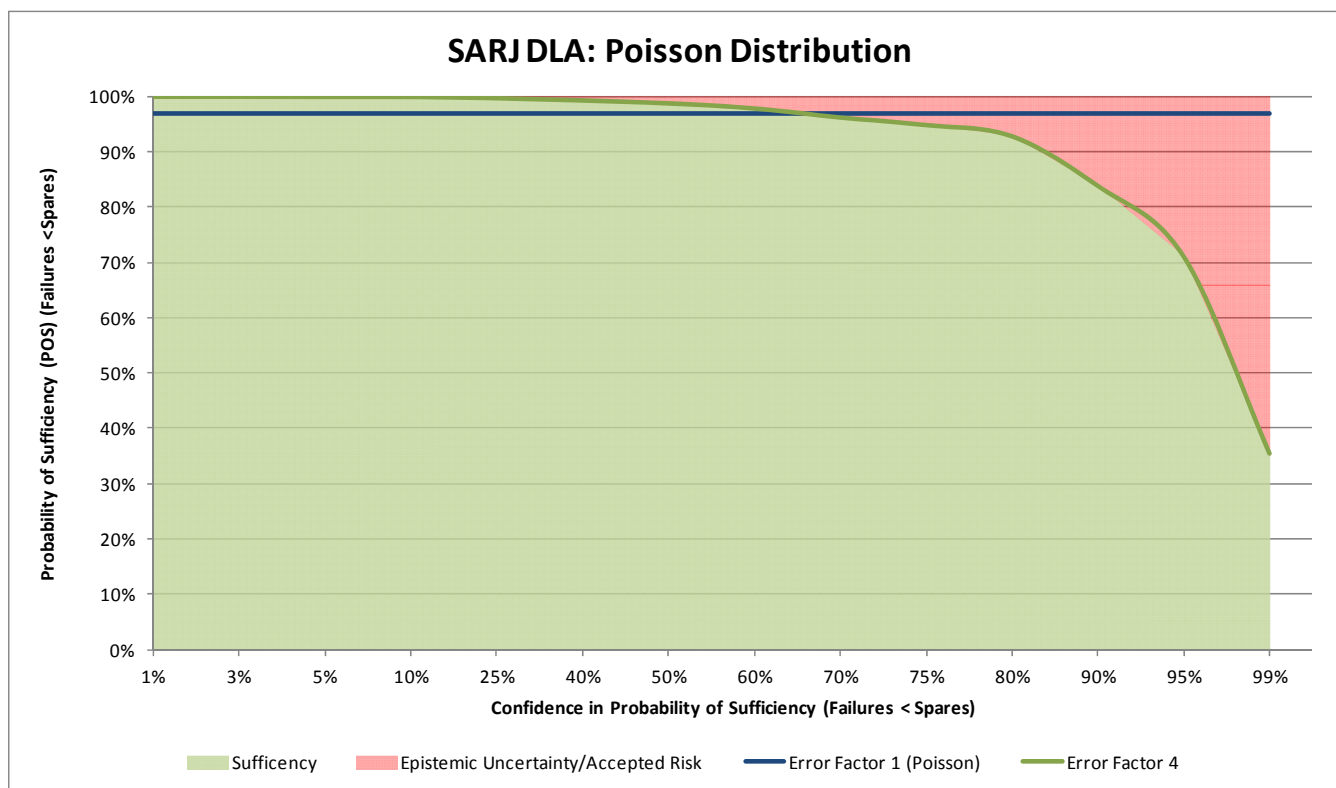




SARJ DLA



Confidence and Probability of Sufficiency through 2020

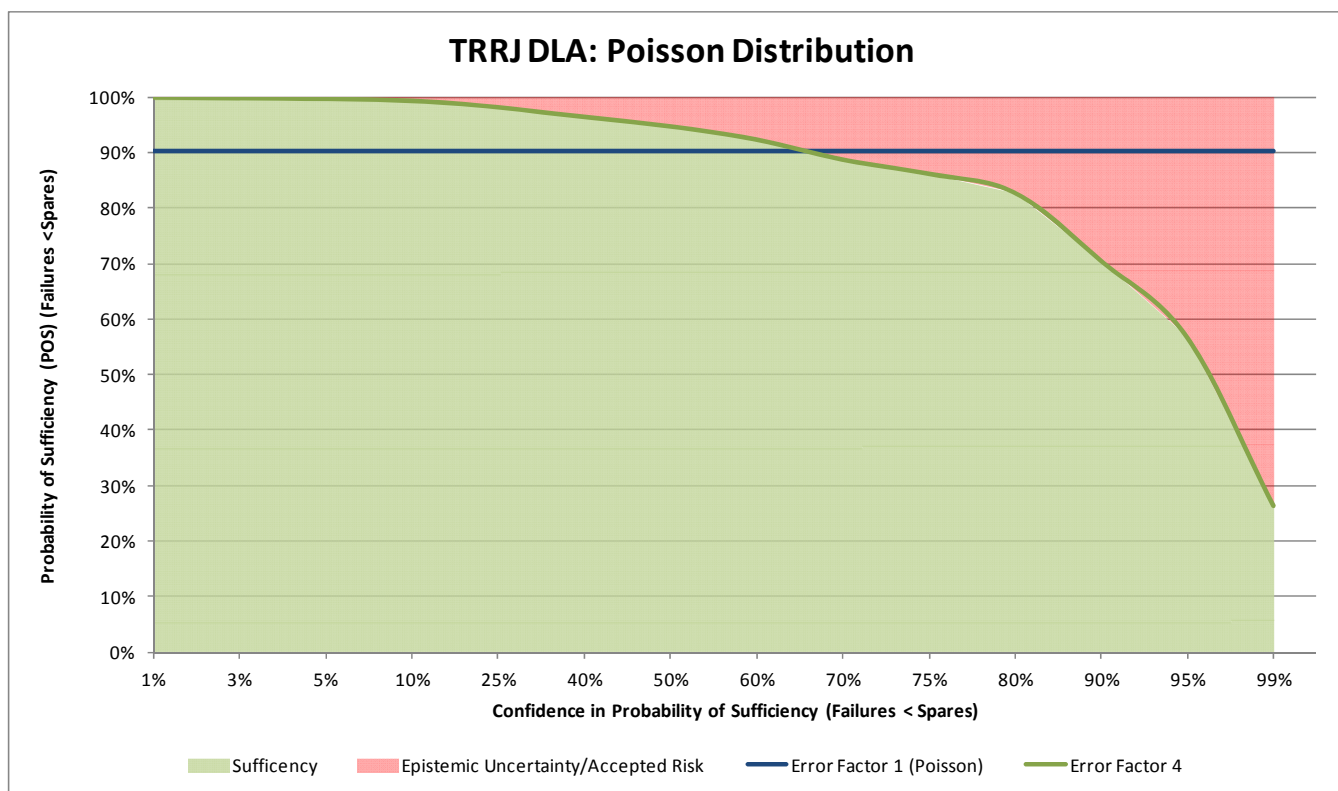




TRRJ DLA



Confidence and Probability of Sufficiency through 2020





Acronyms

Acronym	Description
CT	Confidence Target
EF	Error Factor
IPEHG	Improved Payload Ethernet Hub Gateway
ISS	International Space Station
kF	K Factor
MTBF	Mean Time Between Failure
ORU	Orbital Replacement Unit
PACT	Probability and Confidence Trade-space
POS	Probability of Sufficiency
PMA	Pump Module Assembly
PT	Probability Target
RPCM	Remote Power Control Mechanism
SARJ DLA	Solar Array Rotary Joint Drive Lock Assembly
TRRJ DLA	Thermal Radiator Rotary Joint Drive Lock Assembly